Determining Factors Affecting Carcass Removal And Searching Efficiency During The Post-Construction Monitoring of Wind Farms

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Abstract

Wind energy, although desirable in the goal to slow global warming and climate change, does have the potential to create negative impacts to bird and bat populations sharing the same airspace as the turbines used to generate energy. Quantifying the effects of wind farms on migrating birds and bats is currently done by searching for collision-related fatalities beneath turbines. There are, however, two factors that hinder the accuracy of this technique: carcass removal by scavengers prior to searches and failure to detect carcasses by researches during searches. This study aims to determine which variables affect carcass removal and searcher inefficiency in an attempt to gain a better understanding of how species are being affected by turbines. Carcass removal and searcher efficiency trials were conducted at potential wind farm locations near Chetwynd, BC and variables thought to potentially contribute to these two events were recorded and subsequently analyzed. Smaller carcasses in areas of bare ground were most likely to be scavenged and smaller, less brightly coloured carcasses in areas with high amounts shrub and tall grass were the most likely to be missed during searches. My results provide predictive models that can be effectively used to predict the likelihood of a carcass being scavenged or found by searchers. Findings can also be used to quantify the risk to certain species of being missed during searches if they are colliding with turbines. Habitat modification and the use of dogs during searchers are two other potential mitigation techniques that could be administered to correctly identify the number of collisions occurring.

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Acknowledgements

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Chapter 1 GENERAL INTRODUCTION

1.1 The Growth of Wind Energy

Growing concern over emissions associated with the burning of fossil fuels for energy generation is increasing the desire to develop and implement new 'greener' technologies. These include a number of sustainable means of energy generation, such as run-of-the-river dams, solar power, geothermal energy, and wind power. Wind energy is a common image that comes to mind when one thinks of greener energy, and indeed, it does not produce any emissions during operations. It can also be less intrusive to the environment than drilling for fossil fuels since instalments typically only require road access and habitat clearing underneath the turbines. The average footprint with respect to a wind farm on land (including roads, power line, etc…) is 60 acres per megawatt (AWEA 2008). However, the turbines only generally occupy 5% of this land area, leaving 95% for other uses such as crop cultivation or cattle grazing (Hornburg 2007). Also, this form of energy production, harnessing the power of the wind and transferring it into useable energy, is renewable.

There are, however, some negative aspects to wind energy. Some members of the public find the turbines, especially installed in an area of previously pristine environment, aesthetically unappealing (Krohn et al. 1999). Further, even though the noise produced by each turbine is not extremely loud (45 dB) (CanWEA 2008), some individuals find it distracting and irritating (Wolsink 1999). Finally, the impact on the surrounding wildlife of numerous turbines in a single area is not fully understood, and may pose threats such as movement restrictions, increased predation due to open spaces, and fatalities due to collisions with the turbines themselves (Kuvlesky et al. 2007). Although some studies show that impacts of wind installations on certain species, such as elk, are insignificant (Walter et al. 2006), the impacts on avian species such as birds and bats have not been completely identified. None of the impacts listed above are fully understood, particularly the direct (wildlife collision with turbines) and indirect (displacement and/or avoidance of area by wildlife, habitat loss etc) impact of wind farm placement (GAO 2005; Kingsley et al 2005).

1.2 Risks associated with wind installations

Currently, birds and bats appear to be among the wildlife most heavily affected by turbines (GAO 2005). Some researchers argue that bats are the primary group at risk from wind installations (Johnson et al. 2003; Barclay et al. 2007). Bats appear to be affected by turbines due in part to their flight behaviour when feeding and also to their migration through wind installations. Furthermore, recent research has shown that bat fatalities are sometimes caused by areas of negative pressure created by the turbine blades which trigger the lungs of bats to collapse, a phenomenon known as barotrauma (Baerwald et al. 2008). Nevertheless, migrating birds are also at risk, and monitoring as well as mitigation must be continued for them as well as bats to ensure that all possible risks are being examined (de Lucas et al. 2008). In terms of direct impacts, the number of birds killed per turbine is generally inconsistent, but range from 0 birds/turbine/year to more than 30 birds/turbine/year (Kuvlesky et al. 2007). These inconsistencies are partially attributed to inconsistent monitoring and data collection protocols performed by the researchers (Kuvlesky et al. 2007); however, the research does demonstrate that some sort of impact is occurring, at least at some wind installation locations (de Lucas et al.

2008). Inconsistencies have also been shown to be attributed to the different species of local and migratory birds, the structure of turbines, the layout of turbines, weather and the topography of the wind installation area (Drewitt et al. 2006).

Different species of birds experience different collision risks at wind energy installations. Avery et al. (1977) found that rails and finches were killed more often during periods of good weather, whereas warblers were more at risk during poor weather. Gulls appear to be vulnerable to turbine collision because of their flight height and behaviour; however, very few gull mortalities have been recorded (Airola 1987). Surprisingly, even when waterfowl exist in large groups near wind energy facilities, high numbers of collisions are not recorded (Erickson et al. 2002). Of a greater concern, however, is their avoidance behaviour (Guillemette et al. 1999). Energy is limited during migration, and modifying flight behaviour in order to avoid wind installation areas wastes this valuable energy. Conversely, diurnal raptors appear to be affected more by collisions than by disturbance in migration behaviour (Erickson et al. 2002). Their use of topography and tendency to perch puts them at risk especially when turbines are placed near canyons. Passerines appear to be the most affected by wind turbines. In the United States, 78% of all turbine fatalities involved of songbirds (Erickson et al. 2001). Also, avian species that have aerial display are at a higher risk of colliding with turbines, since these displays distract them as well as put them within the danger area of the turbine blades.

The structure and characteristics of a turbine may affect collision rates. Lattice-style turbines appear to be associated with a higher level of fatalities due to bird species perching within the tower itself (Kingsley et al. 2005). Newer, larger turbines appear to cause the same number of fatalities as the smaller counterparts they have replaced (Howell 1995; Erickson et al. 1999), but the higher efficiency of these larger turbines means fewer turbines per installation, and leads to fewer fatalities per unit of energy produced. Yet, the growing trend of producing even larger-sized turbines may eventually cause more fatalities as the height of each turbine reaches areas of greater migratory movement. Lighting on turbines may lead to more collisions depending on the type of lighting used. Studies have shown that sodium vapour lights attract migrants whereas red strobe lights do not (Kerlinger 2003). Currently, if a turbine is lit, it is normally with a red strobe light (Transport Canada guidelines); however sodium vapour lights are used at substations within the wind installation area, and draw migrants into regions that increase collision rates. Furthermore, it has been suggested that even though red light does not attract migrants it may disorient them, whereas under white and green light birds orient themselves in the appropriate migratory direction (Munro et al. 1997). Modifying the lighting to include green lights instead of red strobe lighting may therefore decrease collision mortality due to bird disorientation at wind installations.

The size and placement of a wind installation plays an important role in avian fatalities. Larger installations with more turbines will generally have more collisions overall than smaller installations with fewer turbines (Kingsley et al. 2005). However, this is true only if installations are placed in areas with the same level of potential risk. Fewer collisions may be recorded from one large-scale wind installation placed in a low-risk area for bird fatalities than will be recorded from many small-scale installations situated in high-risk areas – for example, known high-migratory corridors or important resource areas that attracts or concentrate birds.

Weather has been shown to affect collision rates as well. Reduced visibility associated with poor weather has been shown to cause more mortalities than during clear weather (Avery et al. 1977). This is because birds tend to take a lower flight altitude during inclement weather, putting them in the dangerous area created by the turbines. However, opposite observations have been recorded as well, where mass collisions have occurred during clear weather, attributed to guy-wire collisions (Avery et al. 1977).

Topography plays a role in avian fatalities at wind farm sites due to migratory pathways being associated with specific land features (Alerstam 1990; Kingsley et al. 2001). Ridges, valleys and large bodies of water create optimal conditions for migration (wind updrafts and thermal updrafts) (Alerstam 1990). If the topography of a wind energy installation creates ideal conditions for migration, more avian movement will be seen in the area, creating more chances for collisions.

1.3 Environmental impact assessment of wind installations with respect to birds

It is evident that there are many different factors affecting avian mortality at wind farm installations, and that they are not all fully understood. Historically, in Canada, environmental impact assessments and post-site monitoring of proposed wind farm locations have not been consistent across the country (Table 1-1). This

Table 1-1 A comparison of potential wind farm site assessment techniques currently used provincially with that which is recommended by the federal government (Jacques Whitford 2003, 2004; Neill and Gunther Ltd 2004; Seabreeze Power Corp. 2004; Talbot 2004; Stantec Consulting Ltd 2005). (Tick marks indicate recommended requirements for each category of data collection)

	Provinces						Federal
Data Collection Method	**BC**	**AB**	**SK**	**ON**	**PQ**	**NB**	
Literature review	✓	✓	✓	✓	✓	✓	✓
Interviews		✓	✓	✓	✓	✓	✓
Wildlife survey	✓	✓	✓		✓	✓	
Radar	✓			✓			✓
Point counts			✓	✓			✓
Call-playback survey	✓						
Raptor stand watch	✓			✓			
Winter bird survey				✓			
Breeding bird survey	✓			✓			✓
Level of follow-up*	3	1	1	2	1	3	3

*Number of years of post-construction monitoring requiring the same data collection method advocated for pre-construction monitoring) inconsistency can create discrepancies between regions in the stringency for pre- and post-construction monitoring. The findings in Table 1-1 are based on environmental assessments conducted in different provinces (Quebec, Ontario, BC, New Brunswick, Saskatchewan, and Alberta) between 2003 and 2005 (before the 2007 CWS recommended protocol document was released). Some environmental impact assessments are extremely intensive, studying every possible effect a future wind farm installation might have on the surrounding environment. Others simply refer to other environmental impact assessments done in similar locations or habitats; these extrapolate that the future installation would have no harmful impacts because a comparable assessment did not find any potentially risky or detrimental effects.

The Canadian Wildlife Service released a document recommending protocols for monitoring the impacts of wind turbines on birds (CWS 2007); however, these are just recommended protocols, and are not strictly enforced. Using radar surveys as an example, the protocols state that radar is not generally required. If radar work is required, it recommends performing these daily, but that if this is not possible, less intensive monitoring is acceptable (CWS 2007). Thus, the guidelines are a compromise between extremely intense monitoring favoured by regulators and low-intensity monitoring potentially favoured by industry. The protocols are a definite step forward from before they were released, as can be seen in Table 1-1 where some assessments were extremely lacking in effective assessment techniques. It should be noted that these recommended protocols were created in the uncertainty surrounding the true impacts of turbines on avian populations; yet although thorough, they may not be addressing some of the major risks that have still to be determined.

The disparity seen between the provincial impact assessments of wind farms on migrating birds occurs because the factors influencing avian mortality at wind farms is not fully understood and, therefore, monitoring and predicting such mortality becomes difficult. The protocols recommended by the Canadian Wildlife Service provide guidance based on our current understanding of problems. These protocols offer environmental assessors guidelines to follow in order to obtain an impression of potential impacts, and will hopefully create some monitoring equality throughout Canada. However, it is extremely important to continue to scrutinize the impacts of turbines and the currently used techniques in order to strengthen these guidelines as new information is gathered and obtained. Understanding which techniques must be used, and how to efficiently perform them are essential to ensuring that a wind farm will not have detrimental effects on the wildlife it shares space with.

The direct and indirect impacts associated with wind farms are currently assessed with visual and automated surveys of migratory behaviour of birds and bats. In addition, post-construction monitoring tends to focus on carcass searching as a means of detecting the number of collisions with turbines and the species involved (Kingsley et al. 2005; GAO 2005). However, there are a number of difficulties with these techniques.

1.4 Pre-construction monitoring

One component of an environmental assessment of a potential wind farm site is the monitoring of migratory movement through the area. This can be done during the day, monitoring diurnal raptor movement visually using binoculars, a clinometer, and a range finder. It can also be done nocturnally either through night-vision imagery, thermal imagery, or more commonly, radar detection (Kunz et al. 2007). Radar detection is used to evaluate the avian activity in an area by transmitting radio waves and reading the reflection of these waves once they have encountered an object (bird or bat) (Desholm et al. 2006). This data is then used to quantify how much activity there is in an area, as well as to map general movement patterns. However, in addition to large discrepancies between the power and capacity of the radar systems used, there is general inconsistency between the kind of data collected and the amount of coverage during migratory seasons in which radars are used. Typically, the general direction and number of targets moving past areas of interest are recorded, but detailed tracking is relatively rare. The range of the radars is also generally inconsistent. A very important trade off is seen with respect to the range of the radars and their detection capabilities; the greater the range, the less capable the radar is at detecting smaller sized birds (Schmaljohann et al. 2008). At an even more fundamental level, the number of sample days each season on which radar surveys are conducted is sometimes limited – for example, as low as one to two days at each location per month. This survey frequency is based on the radar survey methods for marbled murrelets which suggests that surveys should be performed at least once during peak seasonal migration (Manley 2006). Such information can give a relative measure of bird traffic in an area, but does it provide sufficient data to classify the degree of, or potential for, risk?

It is also generally agreed upon that there is a fundamental gap linking information found during pre-construction monitoring (such as recording the number of bird passes or mapping migration) to the actual fatalities occurring during post-construction (Kunz et al. 2007). Having the ability to truly understand the impacts of a wind installation project prior to its construction and operation would be the ultimate strategy, however we do not have this ability, and until then, post-monitoring must be conducted in order to fully understand how wind installations are affecting avian species.

1.5 Post-construction monitoring

The primary means of post-construction monitoring of the frequency with which species collide with turbines is through searching for carcasses under turbines. This is most commonly done through direct human carcass searching; however, use of infra-red collision cameras and dog searching are other techniques being further explored.

Thermal infrared imaging detects heat emitted from birds and bats and produces a recognizable image, which is then recorded to a hard drive to be analyzed at a later date (Kunz et al. 2007). Although this technique does offer many potential benefits (useful in pre-construction monitoring of migration and species identification), its price at the current time is extremely high (\$60,000 - \$200,000) (Kunz et al. 2007), which makes it too expensive to be used by most consulting companies during environmental assessments. It also has a very limited visual range which is insufficient for most installations that need to monitor many turbines.

Another method for determining collision frequency is to search for carcasses with dogs. Dogs may be better able to detect carcasses than humans, and therefore increase recovery rates (Arnett 2006). Dogs are not vulnerable to most of the biases that reduce human searching efficiency (size of carcass, colour of carcass, density of ground cover). However, dogs vary in their ability to detect carcasses (Kunz et al. 2007), and in order to overcome this discrepancy, specially trained carcass-searching dogs must be used. This factor creates a problem when taking into account the cost and difficulty of obtaining a specialized dog and the commitment required of keeping such an animal.

Even with these other potential methods for quantifying turbine casualties, carcass searching by humans remains the most commonly used technique because of its ease and relatively low cost. This technique is carried out by searchers sweeping defined areas below turbines and recording any carcasses they encounter. These searches are performed at a frequency of anywhere from every 3 days to every 2 weeks depending on the proposed level of risk at a particular installation (CWS 2007). However, variations in scavenger rates between sites and potential biases in searcher efficiency have resulted in a reduced confidence in this technique (Barrios et al. 2004; GAO 2005). Recent Environment Canada guidelines for wind turbine environmental assessments call for site-specific calibration of these techniques (CWS 2007). Even these calibrations, however, may prove insufficient to truly estimate mortality rates, or bias towards finding carcasses with specific characteristics or carcasses that have fallen in a particular area. It is vital to understand what variables lower the accuracy of carcass searches and whether or not these can be corrected in order to obtain reliable data.

Carcass removal rates are determined prior to, or just following, construction for each site. Many studies have examined these rates, and observed that they fluctuate greatly depending on many different variables (Orloff et al 1992; Higgins et al 1995; Kerlinger 2000; Stickland et al. 2000). Carcass size may play a role in removal with previously conducted studies showing that smaller carcasses are removed more quickly than larger ones (Balcomb 1986; Morrison 2002). In other studies, ground vegetation seems to play a role in whether or not a carcass is scavenged, showing that denser vegetation causes slower removal by scavengers (Tobin et al. 1990; Linz et al. 1991; Cook et al. 2004). Also, studies point to seasonality as a potential factor influencing scavenging rate; yet these seasonal patterns are not always consistent or predictable (Fowler et al. 1997; Bumann et al. 2002; Cook et al. 2004). Although it is apparent that many factors influence carcass removal, correction factors created from pre-construction carcass removal experiments typically do not account for the potential biases associated with particular variables. Furthermore, carcass removal rates are often assumed to be constant from year-to-year, as well as from pre- to post-construction. Scavenger populations, however, fluctuate within and between years (Wilmers et al. 2003), and the effect of construction and operation on these populations is completely unknown; it is therefore unwise to assume the rates will remain unchanged. Determining how much these rates fluctuate, and if the same rates can effectively be applied to sites with similar habitat are important when deciding whether a one-time assessment of rates will provide any useful information, or whether rates need to be taken every year at every site to obtain an accurate idea of the scavenging taking place.

Searching efficiency rates are also calculated prior to construction in order to correct observed numbers. Carcass searching scenarios are created in which a known number of avian carcasses is placed underneath a turbine, which is then searched by another researcher in order to determine the recovery success rate. Searchers vary in their ability to detect and recover carcasses in the field (Morrison et al. 2001) and many studies have been conducted examining this variability (Higgins et al. 1995; Kerlinger 2000; Strickland et al. 2000). Although it is not fully understood why or how searching efficiency is affected, many different variables seem to play a part. Carcass size is one factor that seems to play a role in whether or not a carcass is found. Studies have shown that larger sized carcasses are found more often than those of smaller size (Morrison et al. 2002; Anderson et al. 2004). The amount of brightly coloured plumage present on the carcass may also influence detection, being more noticeable to searchers (Witmer et al. 1995). Ground cover also seems to play a role in the recovery of carcasses. When located in areas of dense vegetation, carcasses are detected less frequently (Wobeser et al. 1992; Higgins et al. 1995). However, the correction factors created from these searcher efficiency trials do not take into account any bias towards carcasses with specific characteristics or carcasses which have fallen in a specific area. They determine the proportion of carcasses that were not found through carcass searching experiments and multiply the number of carcasses found during a real carcass search by this factor (for example if only 50% of the carcasses were recovered during the experimental phase, then carcass searching values would be multiplied by 2 in order to correct them to what is believed to be the true numbers). Such estimates, however, do not reflect the potential for carcasses with particular attributes to be disproportionately missed, while other categories could be fully accounted for.

1.6 Summary

Although wind energy in Canada is still relatively new, it has the potential to grow rapidly due to government priorities to develop clean energy sources (CanWEA 2008). It is imperative that carcass searching results be as accurate as possible in order to fully understand the impact of a particular wind energy installation on the avian community. Without accurate results, detrimental effects may be taking place without the knowledge of those who have the power to mitigate them. It is true that a gap exists between pre-construction monitoring of avian activity and post-construction fatalities, and filling that gap by understanding how one is related to the other is important. However it is essential to accurately identify the fatalities since it are these that could potentially affect avian populations. Performing carcass searching efficiency trials and carcass removal experiments may be insufficient to provide the data needed to accurately understand collision impacts. A fuller understanding of the variables that affect the accuracy of carcass searching is crucial.

1.7 Outline of Thesis

My study aims to provide a clearer understanding of the variables that influence the obtaining of accurate numbers of avian-turbine collision fatalities. In order to achieve this goal, the two factors contributing to a precise impression of avian mortality will be examined: carcass searching efficiency and carcass removal. Although studies have examined these two factors previously, they focused on basic rates of removal or detection, rather than examining the specific variables influencing these rates or creating biases in detail. Understanding which variables contribute specifically to the ability of searchers to locate carcasses, or which increase scavenging rates will help to correct for these biases using variable-weighted models and lead to a more accurate measure of the impacts on the avian community. In addition, it is possible that some of these influencing variables could be used in conjunction with site-specific data to allow managers to gain an understanding of species at risk of being missed due to removal or searcher inefficiency. It is vital to the understanding of the true impacts of turbines on migrating birds that the variables affecting both carcass searching efficiency *and* carcass removal are examined, since they equally contribute to obtaining true casualty values.

1.7.1 Study Site

I conducted experiments were conducted over the course of 2 years (2006/2007) on Wartenbe Ridge, East of Chetwynd, British Columbia [UTM Zone 10 E602854 N6166760] (Figure 1.1). This ridge is part of the 300 MW Dokie Wind Energy installation currently under construction (phase 1 complete by 2009). This ridge is 1200

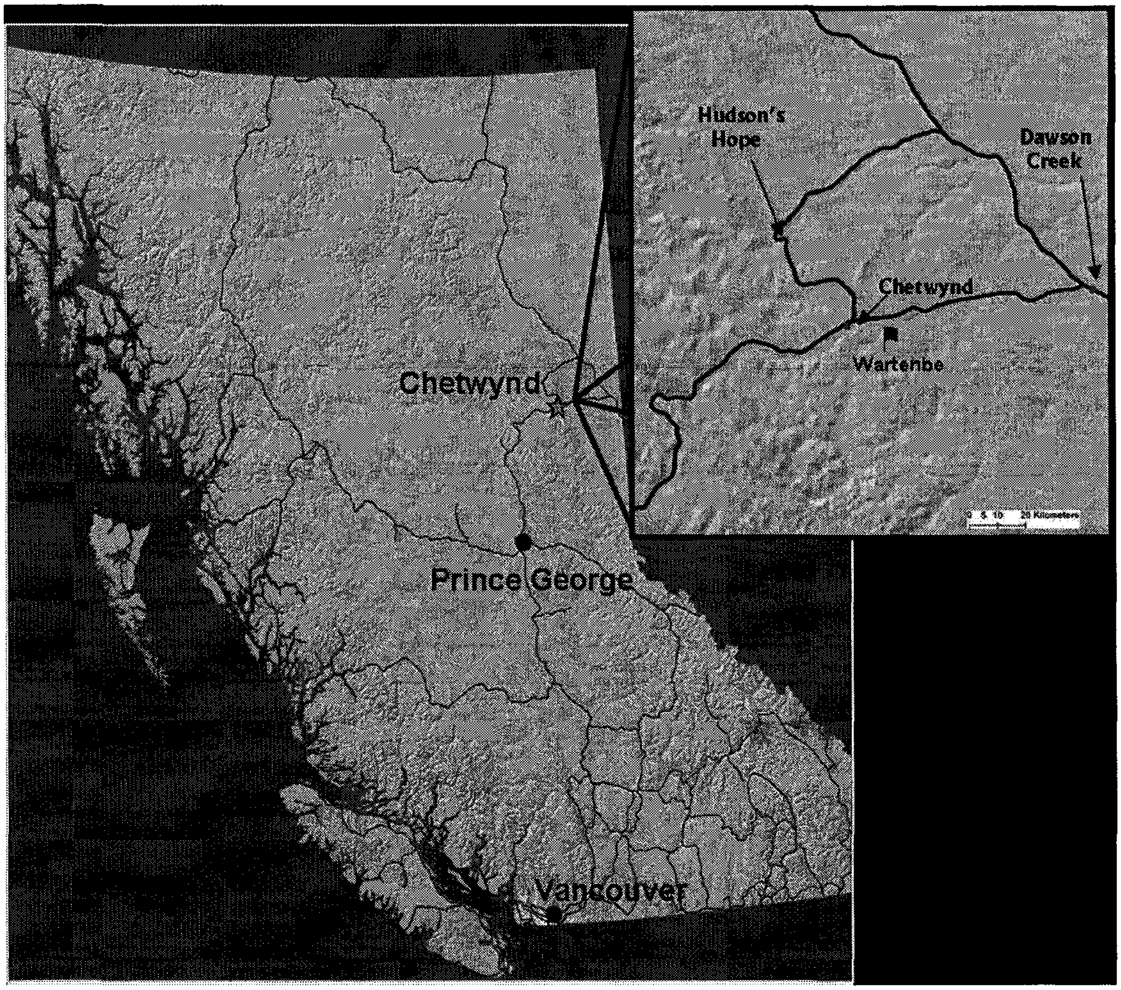

Figure 1.1 Map of study site. Location of Wartenbe Ridge located 40 kilometers west of Chetwynd, BC.

meters above sea level, and is composed of unmanaged pasture land, cut blocks, early successional growth, mature conifer forest and marshes scattered throughout (Figure 1.2). Ungulates such as mule deer (*Odocoileus hemionus*), moose (*Alces alces*), white tailed deer (*Odocoileus virginianus*) and elk (*Cervus canadensis*) and scavengers/predators such as black bear (*Ursus americanus*), grizzly bear (*Ursus arctos horribilis*), grey wolf (*Canis lupus*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*) and common raven (*Corvus corax*) all inhabit the Wartenbe Ridge site. Insects encountered during scavenging experiments were burying beetles (genus *Nicrophorus*) and ants (family *Formicidae*) (AXYS 2006).

1.7.2 Carcass scavenging experiments

In order to determine which variables contribute to the removal of carcasses by scavengers, I placed dead avian species of different sizes and colours in various locations around the study area. Variables related to the characteristics of the bird (size and colour), attributes of the ground cover in a 5 meter radius (percent bare ground, percent tall grass, etc…) and data pertaining to timing (Julian day and year) were recorded for each carcass placed. Carcasses were monitored daily and removal was recorded along with incidental observations regarding other various levels of scavenging.

The variables described above, in combination with the results of whether or not each carcass was completely removed, were analyzed using the methods described below in order to determine which, if any, contribute to whether or not a carcass is likely of being scavenged.

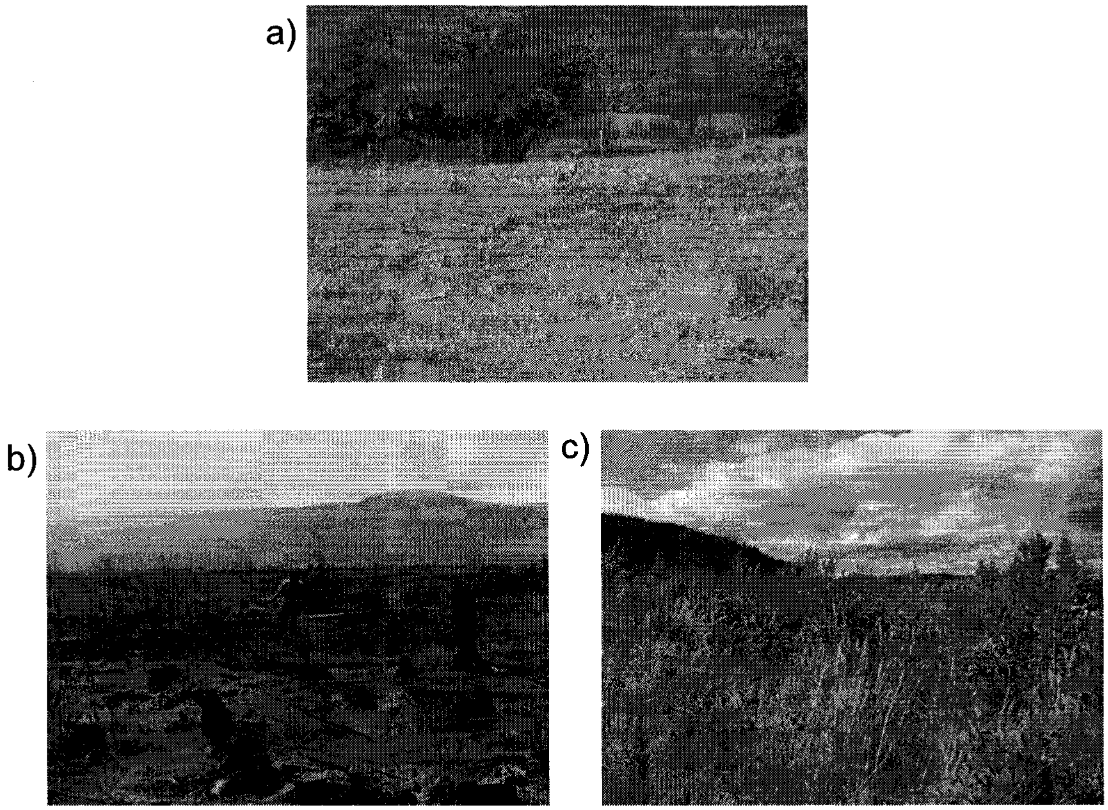

Figure 1.2 **Habitat variation at study site Wartenbe Ridge in Chetwynd, BC. Figure 1a shows pasture land, figure 1b shows cut blocks and figure 1c shows early successional growth, all three of which were present at the study site.**

1.7.3 Searching efficiency experiments

Determining which variables affect searching efficiency requires first that searcher trials be conducted. During a search, 0 to 5 carcasses will be randomly placed within a 50 meter radius. Data recorded for each carcass will include the size (cm) and level of conspicuousness (defined by the amount of brightly coloured feathers present) of each bird, ground cover within a 5 meter radius of where each carcass is dropped, the weather at the time of the search, and the level of experience a specific searcher has. An individual with no knowledge of how many carcasses have been placed then searches the area using a zig-zag technique. This searching technique involves separating the search area into four quadrants and searching by walking back and forth in a zig-zag pattern across each quadrant. Information regarding whether or not a carcass was located is then paired with the specific variables recorded for that carcass and analyzed using the methods described below to determine what affects searcher efficiency.

1.7.4 Analytical techniques

I assessed the relative importance of different variables on the removal of carcasses by scavengers, or the ability of searchers to find carcasses, using Akaike's information criterion. Multiple stepwise regression is commonly used in model creation; however this technique has many drawbacks. There is a bias in parameter estimation, inconsistencies among model selection algorithms and an ultimate confidence in a single best model (Whittingham et al. 2006). It is believed that testing null hypotheses and reporting p-values is not effective in the modeling of predictive and causal relationships (Anderson et al. 2000). Information-theoretic methods do not test hypotheses and instead focus on the relationships between the variables through model selection. The creation of the models requires much more professional judgement, insight and research than hypothesis testing (Anderson et al. 2000). AIC measures the goodness of fit of a series of estimated statistical models (created through scientific reasoning and grouping) and determines the best models by taking into account trade off of precision and complexity of a model (Burnham et al. 2001).

Models were then evaluated for accuracy using the receiver operating characteristic (ROC curve) analysis. ROC curves graphically plot the relationship between sensitivity (true positive ratio) and 1-specificity (false positive ratio) for a binary classifier system (Hanley et al. 1982; Zweig et al. 1993). This technique uses area under the curves as a measure of model accuracy. The higher the area under the curve, the higher the ratio of true positives to false positives, proving the model being tested has good predictive ability. ROC tests the accuracy of a model by testing it against itself; however testing the model using a novel set of data truly shows whether or not it has good predictive ability. In order to determine the predictive ability, models were created using a subset of data (learning set) and were then tested against the data remaining (test set), in an analysis called cross-validation. Good predictive ability of a model indicates that it could be used to generate variable-weighted models. The significant relationships identified during the analysis above where then used to build predictive models. Such variable-weighted models have not yet been applied to wind farm environmental assessments, however they have been used in other studies to predict visibility bias and sightability of elk and big horn sheep (Sightability models - Samuel et al. 1987; Steinhorst et al. 1989; Unsworth et al. 1990; Otten et al. 1993; Bodie et al. 1995; Anderson et al. 1998; Noyes et al. 2000). The methods used in these studies to generate predictive models (using logistic regression coefficients for significant variables determined during the first part of the analysis) were used similarly in this study to create models that would allow researchers to correct for missed carcasses during post-construction searches.

Chapter 2 FACTORS INFLUENCING CARCASS SCAVENGING

2.1 Abstract

Bird and bat collisions are among the most significant environmental impacts a wind farm may have, so being able to quantify the extent of such collisions is critical to designing mitigation programs. The typical technique of quantifying these impacts (searching for carcasses below turbines) may be compromised, though, through carcass removal by scavengers. This study aims to determine which factors (environment, season or attributes of the carcass itself) cause a carcass to be removed. Carcasses were left in different carcass-placement plots and monitored for two weeks for scavenging and complete removal on Wartenbe Ridge, east of Chetwynd BC during the fall of 2006 and the spring and fall of 2007. Variables concerning ground cover, bird characteristics and time were all recorded and used to create AIC_c (Akaike information criterion for small sample sizes) models. Receiver operating characteristic analysis (ROC curve) was conducted in order to determine the level of fit and predictive power of the variable-weighted models found during AIC_c analysis. Carcasses dropped in areas with a high percentage of bare ground, carcasses that were small in size (cm from beak to tail) and carcasses that were placed during the spring were all removed more quickly than other carcasses. When all three variables were tested together, ROC analysis showed that they had good model accuracy, and cross-validation showed that they had strong predictive ability. This suggested that a variable-weighted model could effectively be used to predict removal. By understanding which variables play an important role in carcass removal, our work suggests that the use of correction factors could account for unknown, removed carcasses and may provide more reliable estimates than non-variable loaded correction factors.

2.2 Introduction

Emissions associated with fossil-fuel energy generation are causing an increasing concern over their affect on the environment and global warming. This concern is intensifying the desire to develop and implement more environmentally friendly technologies. This includes a number of sustainable means of energy generation, such as run-of-the-river dams, solar power, geothermal energy, and wind power (Langston 2006). Wind energy is becoming a popular alternate source of energy, as it does not produce any emissions once in operation. There are, however, remaining questions regarding both direct (collision with turbines) and indirect (displacement and/or avoidance of area, habitat loss etc) environmental impacts on wildlife which overlap with the placement of wind installations (GAO 2005; Kingsley et al. 2005; Langston 2006). Direct impacts upon birds and bats – two groups which appear to be among the most affected by turbines (GAO 2005) – are typically measured through searching for collision-victims below turbines following construction of the wind installations (Osborn et al. 2000; Barrios et al. 2004; Mineau 2005). Understanding the cumulative effects of such mortality, especially on species that are threatened or of special concern, requires that the results of such "carcass searches" accurately account for mortality due to collisions. Two factors, however, could decrease the ability to detect these collisions through carcass searches: 1) inability to find carcasses during searches due to searcher inefficiency (to be examined and discussed in the next chapter/paper), and/or 2) removal of carcasses by scavengers prior to formal searches.

In order to evaluate the effect that turbines are having on bird populations, a complete understanding of how long carcasses persist in the landscape following collisions, as well as which factors influence their longevity in the environment, is needed. Many environmental factors also change slightly from year-to-year, which could cause variation in scavenging rates, and these could be further compounded by construction and post-construction activity. Understanding the rate at which carcasses are scavenged is important for determining how often one must search in order to obtain an accurate measure of the number of casualties at a specific turbine. The Canadian Wildlife Service currently recommends that carcass searches be conducted every 3 days in sites with a high level of concern (CWS 2007); but if carcasses in a particular habitat are being removed at higher rates than this, the total number of carcasses attributed to turbine deaths may be underestimated. For example, in a study by Crawford (1971), 94% of experimentally placed carcasses were either removed or partially scavenged during the first evening. Further, if small birds or those with certain characteristics (e.g. bright colouration) are removed rapidly, inappropriate inter-search intervals may be insufficient to assess the effects of a particular wind installation on the avian population.

Scavengers feed more readily on carrion killed through accidents than those killed through predation, since the predator typically eats the entire carcass or guards what remains of it (DeVault et al. 2003). This could cause a shift in scavenging choice from risky predator-killed carrion to safer turbine-killed birds, increasing the rate of carcass scavenging. Furthermore, some scavengers begin to rely on carrion produced during predictable time periods (Wilton 1986; Huggard 1993), and this reliance could be developed during migratory periods when turbine-associated mortality would be higher. Thus, such learning by scavengers could result in ever-increasing removal of carcasses, which could lead to conclusions of decreasing collision rates over time if using standard carcass-searching protocols which do not account for this potential.

Other studies have attempted to determine carcass scavenging rates and used these to create correction coefficients that are applied to carcass numbers to adjust them to realistic levels (Osborn et al. 2000; Barrios et al. 2004; Mineau 2005). Although this partially addresses biases, correction factors often do not adjust for variation in detection or removal based on size, conspicuousness of the carcass, variation in ground cover, time of year etc. It has been shown that all of these variables may affect removal or detection rates (Wilcove 1985; Tobin et al. 1990; Linz et al. 1991; Kostecke et al. 2001; Bumann et al 2002; DeVault et al. 2003 & 2004). It is imperative, therefore, to understand the variables causing carcasses to be scavenged.

Birds with brighter plumage may be more likely to be scavenged, based on likelihood of being found. Further, smaller carcasses may also be easier to remove by scavengers, and thus their presence more likely to go undetected during intermittent searches. Wilcove (1985) found that carcasses placed in areas with no or only low standing vegetation were removed more often and more quickly by scavengers than those dropped in areas with tall grass or shrubs. Thus, I would also predict that surface substrate will likely influence removal rates. Although few studies have been conducted examining the seasonality of scavenging rates, temporal variation in the state of scavengers both within and between years may affect carcass removal rates. Some scavengers may search for carcasses more vigilantly in the fall in preparation for a low food-availability associated with winter.

Conversely, some scavengers may be more active in the spring, attempting to regain body weight after withstanding a hard winter. Further, variation in annual temperature or weather conditions can easily affect individual condition or population numbers, which in turn could result in variation in scavenging rates. DeVault et al. (2004) found that carrion was removed more often and more quickly when temperatures were higher (above 17 °C), which is believed to be associated with decomposition and smell. This illustrates the relationship between carcass removal, temperature and indirectly seasonality.

Using carcasses of varying sizes and colour patterns and placed in habitats that vary in ground cover, this study assesses the variables that influence the removal of carcasses by scavengers. Further, I will determine whether these variables can be used to create correction factors that are efficient in accounting for carcass removal prior to detection during carcass searches, and whether this technique can provide a realistic picture of species that are being affected at wind farm sites.

2.3 Methods

Over the course of 2 years (August & September 2006; May, August & September 2007) 77 bird carcasses (33 in Fall 2006, 26 in Spring 2007, 18 in Fall 2007) were set out, left, and monitored for up to 2 weeks at known sites on Wartenbe Ridge, approximately 20km east of Chetwynd, British Columbia [UTM Zone 10 E602854 N6166760]. This ridge is the proposed site of a wind farm in the Dokie Wind Energy project by EarthFirst Canada. Habitat within the study area varied between mature conifer forest to pasture/grasslands and marshes. Twelve carcass-placement plots were used, incorporating different kinds of habitat from mature forest, young regenerating forest to pasture land. Individual carcass-placement plots consisted of a 100 meter radius circle centred within a particular habitat type, and plots were evenly distributed across the different habitats represented on the ridge. A 100 meter radius area was used because this size allowed for many different placement site locations (with different compositions of ground cover) while still remaining in the same general habitat type. Using a random number generator, I obtained a random bearing from the centre of the carcass-placement plot (0-359°) and random distance (0-99m) with which to place the carcass (hereafter called the individual placement site). Carcasses were obtained from the Ministry of the Environment (Prince George office) and constituted local avian species killed randomly in collisions with cars, powerlines and windows. As a result, the carcasses represented a variety of bird species in a broad array of sizes (from humming birds to an adult 5kg Golden Eagle *Aquila chrysaetos*) and colours (Table 2-1).

Prior to placing each carcass, I recorded its species, size (length from beak to tip of tail) and percent conspicuous colour. I defined this latter measure as the percentage of the bird's plumage that displayed carotenoid-based (bright yellows and reds) or structural colours (bright blues and iridescents), as opposed to the earth tones (blacks, browns, grays) typical of melanin-based colours. The level of conspicuousness was also classified based on the carcass' contrast with the background of the drop site and the orientation of how it was placed. For example, if a carcass contained brightly coloured plumage, but when it was placed, this plumage was hidden, than its level of conspicuousness would be classified lower than if the brightly coloured plumage had been exposed when placed.

Table 2-1 Number of each species used in scavenging experiment. Species are separated into large-sized birds and small-medium-sized birds.

	Species	Scientific Name	Number Used
Large	Great Grey Owl	*Strix nebulosa*	8
	Sharp-shinned Hawk	*Accipiter striatus*	4
	Red-tailed Hawk	*Buteo jamaicensis*	3
	Cooper's Hawk	*Accipiter cooperii*	1
	Golden Eagle	*Aquila chrysaetos*	1
	Herring Gull	*Larus argentatus*	1
	Redhead	*Aythya Americana*	1
Small-Medium	Dark-eyed Junco	*Junco hyemalis*	6
	Lincoln's Sparrow	*Melospiza lincolnii*	6
	Cedar Waxwing	*Bombycilla cedrorum*	4
	MacGillivray's Warbler	*Oporornis tolmiei*	4
	Northern Waterthrush	*Seiurus noveboracensis*	4
	Saw-Whet Owl	*Aegolius acadicus*	4
	Ruby-crowned Kinglet	*Regulus calendula*	3
	Varied Thrush	*Zoothera naevia*	3
	White-crowned Sparrow	*Zonotrichia leucophrys*	3
	Wilson's Warbler	*Wilsonia pusilla*	3
	Black-capped Chickadee	*Poecile atricapillus*	2
	Northern Flicker	*Colaptes auratus*	2
	Orange-crowned Warbler	*Vermivora celata*	2
	Western Tanager	*Piranga ludoviciana*	2
	Blackpoll Warbler	*Dendroica striata*	1
	Evening Grosbeak	*Coccothraustes vespertinus*	1
	Hairy Woodpecker	*Picoides villosus*	1
	House Finch	*Carpodacus mexicanus*	1
	Pine Grosbeak	*Pinicola enucleator*	1
	Purple Finch	*Carpodacus purpureus*	1
	Rufous Hummingbird	*Selasphorus rufus*	1
	Swainson's Thrush	*Catharus ustulatus*	1
	Townsend's Warbler	*Dendroica townsendi*	1
	Tree Swallow	*Tachycineta bicolour*	1
	Yellow-rumped Warbler	*Dendroica coronata*	1

The site did not contain flowers, especially during the time of the experiments (early spring and fall), however some patches of grass nullified brightly-coloured green birds dropped in this situation. Ground cover within a 1 meter radius of the carcass was recorded by observing at random locations (through a 4.3 cm diameter tube held at eye level) and recording the predominant vegetation type at 10 spots within each carcass-placement site. I recorded the date that I initially deposited the carcass, I then revisited the site every day for up to 14 days to determine the status of each carcass. Upon revisiting, a circular path was taken to the location of the dropped carcass so as to not lead potential scavengers directly to the area. For the same reason, if the carcass could be verified as present without walking directly to it, this would be done from a distance of 5 meters. I recorded the time required for each carcass to be removed (complete absence of any evidence of the initial carcass, such that it would represent a "missed" sample in a formal carcass search in an operational wind facility) and made any other observations of note upon each inspection, such as movement of the carcass, partial consumption or insect activity.

2.3.1 Analysis

I used logistic regression Akaike's information criterion (AIC_c) analysis (corrected for small sample size) (Burnham et al 2001) and receiver operating characteristic (ROC) analysis in order to determine which characteristics (bird size/level of conspicuousness, ground cover, and/or date/year) can best predict whether or not a carcass was removed. Logistic regressions were performed using Statistica v.6.1, in order to obtain likelihood values to use in the AIC_c analysis. AIC_c analysis compares the goodness of fit between different models, using a trade off of complexity and precision in each model to do this. AIC_c values were calculated using the following equation (Burnham et al. 2001):

$$AIC_c = -2(\theta) + 2K + \frac{2K(K+1)}{(n-K-1)}$$

Where θ is the log likelihood, K is the number of variables and n is the sample size. AIC_c models were created based on commonalities between variables in order to generate realistic models. The first of five models was based on *bird characteristics* and contained size as well as level of conspicuousness data on each carcass. The second model contained information related to the *ground cover* within a 1 meter radius of where the carcass was dropped. The variables were amount of low-standing vegetation – LSV – (short grass, moss, etc…), bare ground, shrub, tall grass, and logs or other large woody debris. The sub-models were created using similar type of ground cover (bare ground with low-standing vegetation, and tall grass with shrubs) to determine if density of cover affected carcass removal. The third model was created to examine whether time (*seasonality*) had an effect on scavenging. It contained year and day (Julian) related to carcass removal data. The fourth model contained all of the variables (a 'check' to ensure that significant variables explained more variation that simply using the entire model). A final model was created containing all of the significant variables found when the first 3 models were run against each other. This final model was then run against all of the previously listed models to determine whether or not this "*significant variable model*" was able to predict more variation in carcass removals than the others. Models were considered a good fit when the delta AIC_c was less than 2 (Anderson et al. 2000). The model found to explain the most variability was then evaluated for internal accuracy using ROC analysis in SPSS 16.0 for Windows, using area under the curves as a measure of model accuracy. ROC values ranging from 0.5 to 0.7 were considered to have low model accuracy, 0.7 to 0.9 good model accuracy, and > 0.9 high model accuracy (Swets 1988, Manel et al. 2001). To test for external accuracy, the models were tested using cross-validation. This analysis involves creating a model from a proportion of the data (learning set – chosen randomly, using data from both fall and spring experiments) and then testing this model using the remaining data (test set) to determine predictive ability. Models that were able to predict whether or not a carcass was found with more than 70% accuracy were considered good and could therefore effectively be used as correction models.

The contributing variables determined through logistic regression were used to create sightability models (Samuel et al. 1987). These models allow one to estimate targets that would be missed during searches due removal by scavengers prior to searches. In this case, the model would be used to multiply the number of carcasses observed by the inverse probability of their being scavenged, thus estimating the true number of carcasses in a plot (Unsworth et al. 1999). The probability of a carcass being scavenged would be:

$$p = \frac{e^{\mu}}{1 + e^{\mu}}.$$

Where μ is the multiple linear regression equation on factors influencing carcass removal (Samuel et al. 1987, Unsworth et al. 1999):

$$\mu = b_0 + b_1x_1 + b_2x_2 + \ldots b_kx_k$$

2.4 *Results*

2.4.1 Anecdotal Observations

Many different types of scavengers or signs of scavengers were recorded around the placement sites. Insects were present at nearly every placement site. Burying beetles (genus *Nicrophorus)* were observed in 4 of the larger-sized carcasses, but were unable to remove the carcass completely. Ants, however, completely removed some small carcasses within 24 hours of placement. Ant activity to any degree was recorded on 14 carcasses, and was determined to be the cause of removal by searching under logs and other debris for feathers and finding evidence of carcass consumption in ant hills. Ravens were seen scavenging; and coyote tracks and scat and bear tracks were found near some drop sites as well. Although no direct evidence of raptor scavenging was seen, many raptors foraged in the area.

Of the 77 carcasses placed, 41 were scavenged within two weeks of placement. Of the 77 birds, 19 were larger birds (owls, eagles, hawks and waterfowl), with the remaining 58 birds being mixed between a small humming bird and kinglets, including sparrow and warbler species, and larger saw-whet owls and northern flickers (Table 2-2). There were 11 carcasses placed, 9 of which were on larger-sized birds (great grey owls and red tailed hawks), that showed signs of scavenging but were not full removed (Figure 2.1). Among those removed, the average time required for the carcass to disappear was 2.35 days (range of between <1 day and a maximum of 8 days). This average increases slightly to 2.5 when only taking into account larger birds, and remains almost the same as the overall average when only examining smaller birds (2.32). These two size-dependent

Table 2-2 Distibution of large and small-medium sized birds used in carcass removal experiments. Average number of days persisted only refers to those carcasses that were eventually removed.

	# used	% fully removed	average number of days persisted
Large birds	19	32	2.5
Small-medium birds	58	48	2.32

Figure 2.1 **Partially scavenged great grey owl (*Strix nebulosa*) carcass. Scavengers are believed to be common ravens (*Corvus corax*) based on visual identification during surveys**

averages are not statistically different ($p = 0.88$) when tested using a two-tailed t-test (df = 32; $t_{crit} = 2.04$). It appears, therefore, that the rate at which carcasses are removed is not dependent on size. It also appears that scavenging happens quite early (< 3 days) or not at all (> 14 days).

2.4.2 Temporal Variation in carcass removal (Julian date)

The model containing only the variable, *Julian date*, (Model 1.1) had the lowest delta AIC_c score and the highest weight during the running of the first AIC_c (Table 2.3). This reflected that carcasses were more likely to be completely removed with lower Julian date (in the spring) than higher Julian date (fall). Due to its low delta AIC_c score, it was included in the Significant Variable Model for the second analysis. The model containing both *Julian date* and *year* also had a delta AIC_c score lower than 2, however, this could be attributed to the fact that *Julian date* explains the most variability out of all of the variables (delta AIC_c of zero), and is causing the low delta AIC_c and high weight seen in this particular model. It is for this reason that *year* was left out of the *Significant Variable Model.*

2.4.3 Attributes of the Bird (Size)

Size had the second highest weight of all of the models (Table 2-3), indicating that small birds are most likely to be removed by scavengers. This was the second variable to be included in the Significant Variable Model.

Table 2-3 Initial AIC models under Attributes of the bird, ground cover, and temporal variation affecting removal. The model with Julian day alone under Temporal Variation had the lowest ΔAICc, but length of the bird, % bare ground around the carcass, and Julian day % year all had ΔAICc below 2.0.

	Log likelihood	AIC_c	ΔAIC_c	weight
Temporal variation				
Model 1.1 - Julian day	-51.17	104.40	**0**	0.27
Model 1.2 - Julian day & year	-50.61	105.38	**0.99**	0.16
Model 1.3 - Year	-53.87	109.80	5.41	0.02
Attributes of the bird				
Model 2.1 - length from beak to tail (cm)	-51.40	104.85	**0.45**	0.216
Model 2.2 - %conspicuousness & length from beak to tail (cm)	-51.40	106.95	2.56	0.0756
Model 2.3 – % conspicuousness	-53.95	109.96	5.56	0.017
Attributes of ground cover				
Model 3.1 - % bare ground	-51.76	105.57	**1.17**	0.15
Model 3.2 - % low standing vegetation & % bare ground	-51.48	107.13	2.73	0.07
Model 3.3 - % low standing vegetation	-54.70	111.46	7.06	0.008
Model 3.4 - % shrub & % tall grass	-52.58	111.48	7.08	0.008
Model 3.5 - % low standing vegetation & % bare ground & % shrub & % tall grass & % log	-50.98	112.80	8.40	0.004

2.4.4 Attributes of Ground Cover (Bare ground)

The model which had the third strongest weight was the one containing the bare ground variable (Model 3.1) (Table 2-3). Carcasses were more likely to be removed when they fell in areas with a high amount of bare ground within 1 m of the carcass. Its low AICc score made it the third and final variable to be included in the Significant Variable Model.

2.4.5 Significant Variable Model

The *significant variable model* contained the three variables mentioned above, creating a model to possibly explain the most variation. When this new model and a *full model* (containing all of the possible variables in the experiment) were compared against each other as well as the eleven models from the first AIC_c analysis, the *significant variable model* had an extremely low delta AICc score, and a very high weight (0.95) (Table 2-4), leaving all the other models to explain very small proportions of the variance. The *full model* was including during this analysis to determine whether the *significant variable model* explained more variance than simply including every variable possible.

When the *Significant Variable Model* was analysed using ROC, the area under the curve was 0.77, (Figure 2.2) classifying it as having good model accuracy (Swets 1988, Manel et al. 2001). When tested using cross-validation, this model showed good predictive ability (Table 2-5) correctly predicting scavenged carcasses 70.00 % of the time and correctly predicting non-scavenged carcasses 84.21 % of the time.

Table 2-4 Second AIC model set adding full model and a model composed of the main significant effects from Table 2.3. The model with the three most significant variables from the first analysis had the lowest ΔAIC_c as well as the only ΔAIC_c below 2.0. ΔAIC_c values for all models included in Table 2.3 change from their initial values due to the *Significant Variable Model* having the lowest AIC_c value.

	Log likelihood	AIC_c	ΔAIC_c	weight
Temporal variation				
Model 1.1 - Julian day & year	-50.61	105.38	10.36	0.005
Model 1.2 - Julian day	-51.17	104.40	9.37	0.009
Model 1.3 - Year	-53.87	109.80	14.77	0.0006
Attributes of the bird				
Model 2.1 - % conspicuousness	-53.95	109.96	14.93	0.0005
Model 2.2 – length from beak to tail (cm)	-51.40	106.95	11.92	0.002
Model 2.3 - %conspicuousness & length from beak to tail (cm)	-51.40	104.85	9.82	0.007
Attributes of ground cover				
Model 3.1 - % low standing vegetation	-54.70	111.46	16.43	0.0003
Model 3.2 - % low standing vegetation & % bare ground	-51.48	107.13	12.10	0.002
Model 3.3 - % shrub & % tall grass	-52.58	111.48	16.45	0.0003
Model 3.4 - % low standing vegetation & % bare ground & % shrub & % tall grass & % log	-50.98	112.80	17.77	0.0001
Model 3.5 - % bare ground	-51.76	105.57	10.54	0.005
Full model – all above variables (Model 4)	-41.21	103.07	8.05	0.02
Significant Variable Model - Length from beak to tail (cm) & % bare ground & Julian day (Model 5)	-44.35	95.03	**0**	0.95

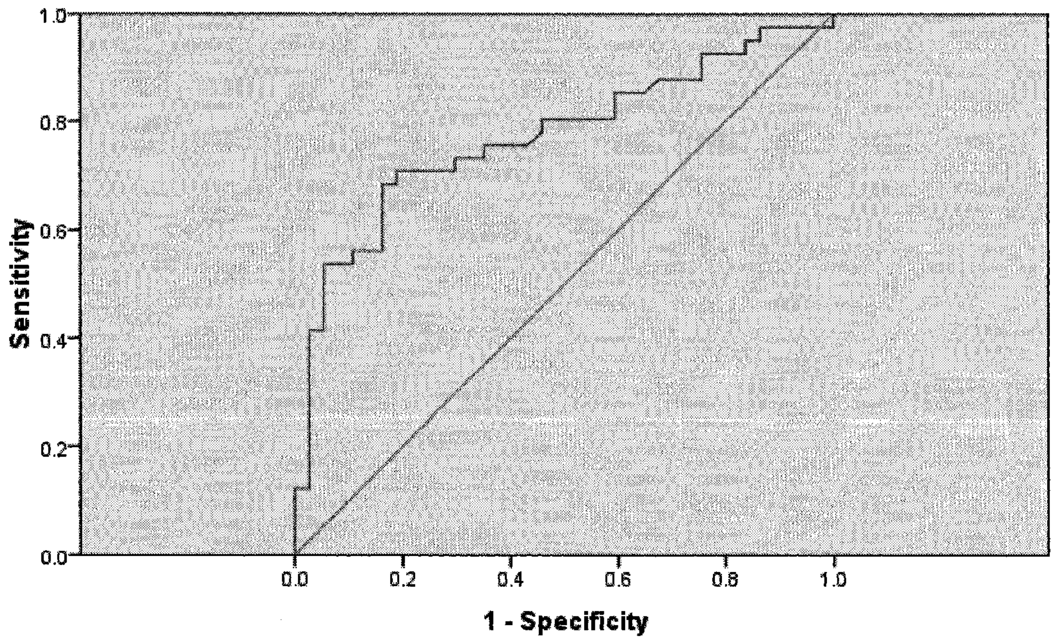

Figure 2.2 **Receiver operating characteristic analysis (ROC curve) of the *Significant Variable Model* showing true positive (sensitivity) vs. false positive (1-specificity). The area under the curve is 0.773.**

Table 2-5 Cross-validation results using the 'significant variable model' showing percent correct prediction for carcasses that were scavenged and those that were not scavenged.

		Observed		
		Scavenged	**Not Scavenged**	**Percent Correct**
Predicted	**Scavenged**	14	3	70.00
	Not Scavenged	6	16	84.21

The variables determined to be significantly contributing to whether or not a carcass is scavenged were then paired with their respective coefficients, determined during logistic regression, to create a model for predicting the probability of a carcass being scavenged:

$$\mu = 5.21 - 0.02(\text{Julian Day}) - 0.04(\text{size from beak to tail}) + 0.20(\%\ \text{bare ground}).$$

Negative coefficients indicate that larger values of that variable cause scavenging likelihood to decrease, whereas positive coefficients cause scavenging likelihood to increase (Samuel et al. 1987). Using this to calculate the probability of scavenging (see Methods), experimenters should be able to adjust numbers of carcasses observed to compensate for biases in detection due to removal of carcasses by scavengers.

2.5 Discussion

After analysing the results, it appears that a combination of the size of bird (cm from beak to tail), date of drop (seasonality), and percentage of bare ground at the drop site is capable of reliably explaining carcass removal within my study area. Together, these attributes are capable of producing a model accurate enough to have good predictive ability when classifying removal in known experiments.

In terms of carcass characteristics, smaller carcasses were more likely to be removed than larger carcasses. Observations in the field showed that smaller carcasses were more easily removed by a greater number of scavengers (insects, ravens, and small mammals) and therefore had a higher likelihood of being removed than larger carcasses. Crawford (1971) observed experimentally-placed bird carcasses to be most often removed by crows (*Corvus brachyrhynchos*) and great-horned owls (*Bubo virginianus)*. Smaller carcasses would be entirely removed by larger scavengers, or pulled under logs or rocks by insects. Similar to our findings, Morrison (2002) reported that small to medium-sized carcasses were more likely to be removed compared to larger birds. In my study, larger carcasses showed signs of being consumed, however enough of the carcass remained when checked to still classify it as a dead bird (which would be done in a real life, turbine fatality carcass scenario). Larger carcasses also showed signs of insect activity, however not enough of these carcasses were displaced by this method to render it completely undetectable during a hypothetical search. Such insect scavenging, however, could make such specimens more obscure; ants and other insects have been observed consuming the feathers of bird carcasses, thus making them harder to spot in surveys (Rosene et al. 1963). In a study done by Balcomb (1986), it was reported that 62 % to 92 % of small songbird carcasses were removed from agricultural fields (similar terrain to that at Wartenbe ridge) after 24 hours with 100 % being removed after 72 hours. On Wartenbe, 48% of the small sized birds used were scavenged, and 75% of these were removed within the first 3 days. If most of the smaller bird carcasses are being removed every 1-3 days, then searching for carcasses in a real-life scenario in 3 days would be ineffective. Also, creating a coefficient to apply to the total number of birds found (after searching every 2 weeks) in order to quantify the real number of birds being killed by turbines would not allow for a complete understanding of the species being affected. For example, if turbines are killing many small birds and only a few larger birds, using a coefficient to adjust searching results would not give a realistic understanding of the species being affected. This coefficient is only capable of determining that for every bird found during a search, a certain number of other birds (of unknown size) were killed (but removed). All of the information associated with knowing that many birds of a smaller species were being killed is lost when they are scavenged and not present during searches.

Peterson et al. (2001) found that larger carcasses (duck-sized) were removed in very short periods of time (< 72 hours) by raptors; however, these findings were during winter months. Very few of the larger-sized carcasses were completely removed in my study (31%) which might suggest that removal by raptors shows seasonal patterns. More normally observed are larger, more conspicuous carcasses being scavenged first, such as those found on the Serengeti Plains in Africa (Houston 1979), however observations such as these may be biased, since they are far easier to notice than smaller, less conspicuous carcasses.

Carcasses that were dropped in sites with a high percentage of bare ground within a 1 meter radius tended to be scavenged more than those which were dropped in sites that had less bare ground and a higher percentage of other vegetation types. Carcasses that are more exposed are perhaps more readily detected by scavengers, and are therefore removed more than those in areas containing a higher proportion of dense vegetation types. The same was found in a study by Cook et al. (2004), where it took twice as long in forests and three times as long in sagebrush for bovine fetuses to be removed than in grasslands. They hypothesized that forests caused low visibility for avian scavengers and sagebrush caused scavenging to be more difficult than in grasslands. Tobin et al. (1990) found that in cherry orchards with bare ground under the canopy, carcasses were removed in 24 hours, as opposed to other orchards with different vegetation types under the canopy, in which carcasses remained for 8.2 days. When examining scavenging rates in marshes, Linz et al. (1991) found that carcasses that were placed in deeper water were scavenged less often than those placed in shallower water. This suggests that carcasses that are more hidden or harder to access are removed at a slower rate than those that are more available to scavengers. Bumann et al. (2002) found that the distance from a carcass to the edge of a habitat did not make a difference to scavenging rates. This could mean that bare ground does not increase removal by creating easier access to carrion; it does so by increasing the visibility of the carcass to scavengers. Wilcove (1985) discussed that avian scavengers (such as the Common Raven) are more active in areas that have been modified by human activities, with less intact forested area. Creating large areas of bare ground and low standing vegetation - as will likely happen when the construction of the turbines occurs - may increase the activity of some scavengers, causing carcasses to be removed at an even higher rate.

Finally, carcasses tended to be completely removed at higher rates in the spring (April, May) than in the fall (August, September, October). Warmer temperatures might increase scent dispersal and scavenger activity, which would result in higher scavenging rates (Bumann et al. 2002). Although August was normally warm, September and October were frequently cooler than spring temperatures in the study site. In a study by Putman (1976, cited in DeVault 2003), 100% of placed carcasses were removed during the winter and spring, while 64% of carcasses placed in fields were removed during the summer. Since winter months are obviously less warm than summer months, perhaps a factor other than temperature is affecting scavenging frequency, such as prey availability. Cook et al. (2004) found that carcasses were removed more quickly during the cooler months, attributing this to the higher level of aggressiveness and hunger experienced by scavengers during this time. Finally, Fowler et al. (1997) also found trends with respect to weather and scavenging rates but noted that different patterns were seen in different studies, and no conclusive findings could be determined. Obviously there are some conflicting results regarding the effects of temperature on scavenging activity, and more site-specific understanding of these rates will need to be determined to effectively understand carcass loss if turbine-collisions are to be accurately determined.

It is important to note that the temperatures of the carcasses were far lower than those of freshly-killed birds, since they had been previously frozen. Van Pelt et al (1995) and Bumann et al (2002) stipulate that perhaps this reduces the scavenging rate, since fresher carcasses would be more appealing and perhaps more attractive to scavengers. This point however, only means that this study was conservative in estimating the removal rates; natural carcasses (being warmer) might be removed more quickly. Since the carcasses persisted perhaps slightly longer than they would have naturally, removal rate may have been more staggered allowing variables to be noted and their significance to be determined. One means of testing whether previous freezing of carcasses affects removal would be to compare freshly killed birds (obtained from turbine or building collisions) and previously frozen birds to determine if there is differential detection and removal rate.

Once variables that affect removal rates are identified, the primary concern is whether these can be used to derive correction factors to account for carcasses lost between search periods. To test for internal validity, I used ROC curve analysis. This tests if the model created with the significant variables can accurately account for the variation in the data used to build it. The result was positive, producing more true positives than false positives, suggesting that the *Significant Variable Model* has strong internal accuracy. In order to determine if this model had strong external validity, cross-validation was used. Once again, the result was positive, with the model capable of accurately predicting results 70 – 84 % of the time. These results suggest that this model is capable of building predictive models to account for carcass removal by scavengers. Such models weight the influence of each variable on predicting removal, and so should represent a fairly accurate "correction factor" to assess the ability to predict removal of novel carcasses with similar attributes. The model created and listed above could successfully be used to predict scavenging likelihood. Additionally, it is also possible to use these correction factors to determine if any species of birds in an area of concern have a high risk of being scavenged if they are, in fact, colliding with turbines.

One potential problem would be that a high percentage of bare ground around a bird carcass has been found to increase the likelihood of it being found by searchers (Chapter 3). However as is seen in this study, this same ground cover is likely to increase the scavenging of carcasses. Deciding whether to modify the ground cover in a way to increase searching efficiency or in a way to limit scavenging rates will be difficult, and perhaps there is a middle ground that will involve creating a ground cover that is good for searcher recovery (therefore increasing scavenging rates) and perform searches more often. Fencing areas around the base of turbines and keeping the ground bare to increase searching efficiency but reducing scavenging activity is an option, however it is time consuming and expensive to erect fences and maintain appropriate ground cover. Although logistically challenging, fencing a subset of the towers may be worth the effort and expense in order to get more accurate information on direct impacts.

2.5.1 Management Strategies

The relative importance of specific variables that predict removal in this study are likely site-specific. The species of scavengers present at a specific location will determine what carrion is consumed. Perhaps in an area with larger scavengers and fewer insects, larger bird carcasses would be removed more often than smaller ones. It is for these reasons that similar carcass removal trials must be carried out at each new site to determine which characteristics influence scavenging, as well as to derive the variable loadings to be used in developing correction models. Despite this, the variables that I found to influence removal rates are consistent with other research on scavenger behaviour – these variables may likely contribute to carcass removal at other locations, and should be collected when conducted removal trials to determine local correction values.

Once the influence of variables has been determined, a sightabilty model could be created in the same manner as outlined here, by first determining the contributing variables through AIC and determining the loadings through logistic regression analysis. This model can then be used to predict scavenging likelihood, and this probability used to estimate the numbers of carcasses missed due to removal by scavengers, similar to models used to estimate ungulate populations that suffer detection biases during aerial surveys (Unsworth et al. 1990, 1999). Should these models prove accurate, similar programs could be developed that allow managers to specify the variables and their influence on carcass removal at individual installations, thus allowing an estimation of mortality that accounts for potential carcass removal.

These findings can be used in other, extremely useful ways as well. Using the variables found to increase the probability of a carcass being scavenged, a manager could determine the likelihood of removal for an area (one containing higher proportions of bare ground such as in this experiment) or the likelihood of removal for a species known to be present at the site (smaller-sized birds in this study). If there are many species with a high likelihood of being removed in a management area, perhaps more intense strategies could be enacted to compensate for this (higher search frequency). In the current study, carcasses were either removed quickly, or they persisted for the duration of observations. Depending on the target species of concern, and where they fall in the likelihood of removal, managers could use this information to set inter-search intervals – i.e. if target species are small and the area is largely open, inter-search intervals of two days would be optimal for detection, whereas if the target species are larger, greater time between searches would not diminish the ability of managers to detect collisions.

Chapter 3 FACTORS INFLUENCING SEARCHING EFFICIENCY

3.1 Abstract

Searching for carcasses below turbines is the typical technique of quantifying bird and bat collisions with turbines. However, the efficiency of this technique at producing accurate results has been questioned due to inefficient carcass detection by searchers. To determine variables that influence whether a carcass is detected during searches, I conducted search trials using placed carcasses in 50 meter radius plots on Wartenbe Ridge, east of Chetwynd BC during the fall of 2006 and the spring and fall of 2007. AIC_c (Akaike information criterion for small sample sizes) analysis was used to compare different models which potentially explain the variability seen in carcass searching efficiency. Variables concerning ground cover, bird characteristics, weather, and searcher experience were all recorded and used to create AIC_c models. Receiver operating characteristic (ROC) analysis was then performed to test for internal accuracy and cross-validation was used to test for external accuracy as well as if a variable-weighted model (determined during the AIC_c analysis) could be created that was capable of accurately predicting whether or not individual carcasses would be found. The variables that were determined to affect searcher efficiency were carcass size (cm from beak to tail) (larger sized birds were more likely to be found), and/or level of conspicuousness (brightly coloured birds were more likely to be found), and/or the percent ground covered by tall grass and shrubs (higher percentages of these vegetation types caused carcasses to be unlikely to be found). The ROC analysis and cross-validation results suggest that a model containing all of these significant variables is capable of predicting whether or not a carcass will be found, thus allowing for the possibility of creating "correction factors" for undetected carcasses, using a weighted-

variable model, also developed in this study. These findings also allow planners to manipulate features which maximizes carcass searching efficiency prior to searches being conducted.

3.2 Introduction

Birds and bats appear to be among the wildlife most directly affected by wind turbines (GAO 2005; Baerwald et al. 2008), and the degree of their impact is typically assessed through searching and recording the number of collision-casualties found below turbines once the farm is operational (Osborn et al. 2000; Barrios et al. 2004; Mineau 2005). It is extremely important that these searches provide accurate results of collision mortality, especially when species are threatened or of special concern. Without fully understanding mortality at wind farm installations, potential cumulative effects cannot be fully understood. Performing carcass searches and obtaining highly accurate results, however, is not a simple task. There are two factors that could decrease the successful detection of carcasses during searches, thus creating an inaccurate image of collision risk: 1) carcasses are not found during searches due to searcher inefficiency (Osborn et al. 2000), and/or 2) carcasses are removed by scavengers prior to formal searches (see Chapter 2). Quantifying collisions with turbines is one of the biggest challenges to determining direct impacts of wind installations in the growing wind energy industry, yet in order to evaluate the effect of such collisions on bird populations, a complete understanding of which and to what degree variables affect the ability of searchers to detect carcasses is needed. Carcass searches may potentially be inaccurate or imprecise, as many factors, including characteristics of the carcass, ground cover, and even searcher experience may influence whether or not a carcass is found during searches (Wobeser et al. 1992). Understanding how these factors affect detection rates could help mitigate searcher inefficiency, either through habitat modification that increases detection rates or through the creation of mathematical correction factors to account for missed carcasses

(Kunz et al. 2007). Currently, no habitat modification has been reported under turbines in search areas, and searches are being conducted in whatever habitat naturally occurs under each turbine (some turbines do have gravel pads at their base, but this is not a required practice). The intervals between searches has become shorter due to the greater understanding and as compensation for carcass removal (Chapter 2); however, if searches are still not being conducted efficiently, accurate results will not be obtained regardless of inter-search interval.

Other studies have attempted to determine the efficiency of carcass searching, and have used their results to create correlation coefficients that are then applied to real-life carcass numbers to adjust them to realistic levels (Strickland et al. 2002). Unfortunately, this does not entirely fix the problem, since correction factors often do not adjust for variation in searching efficiency based on characteristics that affect detection (such as size or conspicuousness of the carcass, variation in ground cover, searcher experience etc) (Wilcove 1985; Tobin et al. 1990; Linz et al. 1991; Kostecke et al. 2001; Bumann et al 2002; DeVault et al. 2003 & 2004). It is extremely important, therefore, to understand to what degree each variable affects searcher efficiency. Even though these correction factors have not been used yet in wind farm assessment, studies have been conducted in other areas which create variable-weighted models in order to predict realistic numbers of importance (Samuel et al. 1987; Steinhorst et al. 1989; Unsworth et al. 1990; Otten et al. 1993; Bodie et al. 1995; Anderson et al. 1998; Noyes et al. 2000).

Many studies have been conducted examining, in part, searcher efficiency (Wobeser et al. 1992; Higgins et al. 1995; Witmer et al. 1995; Fowler et al. 1997; Morrison 2002). Some of these studies touch on the effects of carcass size on searcher efficiency and carcass detection. It is assumed that larger carcasses would be found more often than smaller carcasses because larger objects are more easily detected. Some studies have shown that the more conspicuous (brightly coloured) an animal, the more likely it will be to be noticed by other animals (Craig et al. 1994; Thetmeyer et al. 1995). It would be expected that more conspicuous carcasses may be found more often than less conspicuous ones because the brighter colours may attract searcher attention. Finally, studies have shown that carcass estimates are affected by vegetative cover (Wobeser et al. 1992, Philibert et al. 1993) and I would therefore predict that ground cover will prove to be a significant variable in whether or not a carcass is found.

Using carcasses of varying sizes and colour patterns, placing these in habitats that vary in ground cover, and using different searchers, I will assess the variables that influence searching efficiency. Further, I will determine whether these variables can be used to create correction factors that are capable of accurately determining the likelihood a carcass is detected during searches. I will also investigate other potential management strategies that could be used to better understand the true impacts of turbines on migrating birds.

3.3 Methods

Over the course of 2 years (Fall 2006 and Spring 2007), carcass search efficiency trials were conducted on Wartenbe Ridge, East of Chetwynd, British Columbia [UTM Zone 10 E602854 N6166760]. This ridge is part of the 300 MW Dokie Wind Energy installation currently under construction (phase 1 complete by 2009). To test searcher efficiency, simulated search plots were marked out (50 meter radius) and I placed carcasses at random sites within the plot. To determine these locations, I used a random number generator to create degree/angle from plot center and then number of paces from the center of the search plot from which to place the carcass (Figure 3.1). This technique allowed the experimenter to relocate each carcass, whether the searcher found the carcass or not. Search plots contained habitats representative of those found below turbines – ranging from bare ground to low shrub cover. Search plots were designed to mimic an approximate area under a turbine that would typically be formally searched. The general habitat for each search plot was recorded as well as the UTM coordinates of the center. The ground cover within a 0.5 meter radius centred on each placed carcass was recorded in percentages of specific vegetation type (ex: low and tall grasses, shrubs, bare ground, etc…) in order to determine if particular vegetation affects carcass discovery. For each trial, I placed between 0-5 carcasses (randomly determined) within each search plot; this emulates realistic kill rates reported at wind installations.

The carcasses used varied in species, size and colour; the goal was to determine whether or not a bias exists towards finding only larger-sized birds (Barrios et al 2004) or birds of

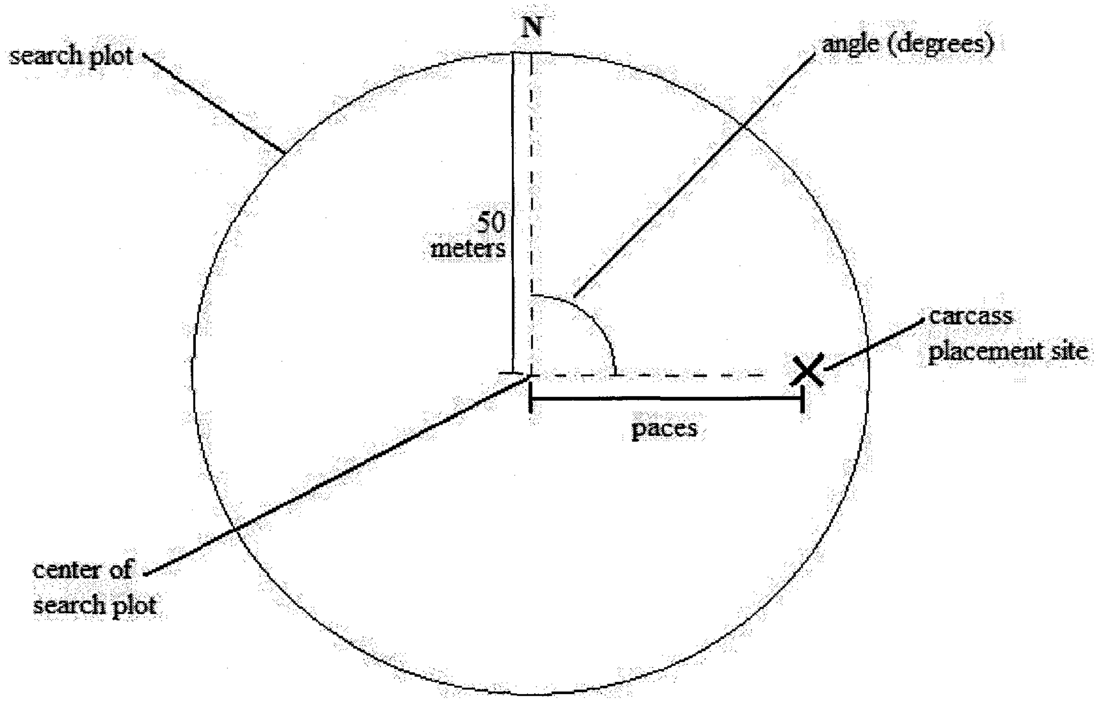

Figure 3.1 Diagram of search plot used in carcass searching efficiency trials. Plots were 50 meters in diameter. Each carcass placement site was determined using an angle in degrees and a number of paces (produced by a random number generator) measured from the center of each plot.

more conspicuous colours. Size was recorded in centimetres from beak to tail. I defined the level of conspicuous colour as the percentage of conspicuous colour of each bird carcass – defined as carotinoid-based (bright yellows and reds) or structural colours (blues and iridescents) typical of sexually selected characters and sharply contrasting with the earth tones (blacks, browns, grays) typical of melanin-based colours (Gill 2006). Six of the 'carcasses' were fabricated bird carcasses, used to increase the sample size. They were made from different coloured fabrics (some very bright, and others duller) and made in different sizes in order to simulate true bird carcasses. A total of 104 carcasses were placed in searching surveys.

Each searcher walked the transect in a zigzag pattern which is the most commonly used technique when carcass searching. This technique involves splitting the transect into four quadrants and walking each quadrant from the outside to inside (or inside to outside) in a zigzag pattern (Figure 3.2). Each searcher had one hour to complete the search of the entire plot. Finally, temperature, wind, precipitation and cloud cover were recorded during each search.

3.3.1 Analysis

I used logistic regression and Akaike information criterion (AIC_c) analysis (corrected for small sample size) (Burnham et al 2001) in order to determine which characteristics (bird size/level of conspicuousness, ground cover, weather, and/or searcher experience) affect whether or not a carcass is found. AIC_c requires likelihood values which were obtained

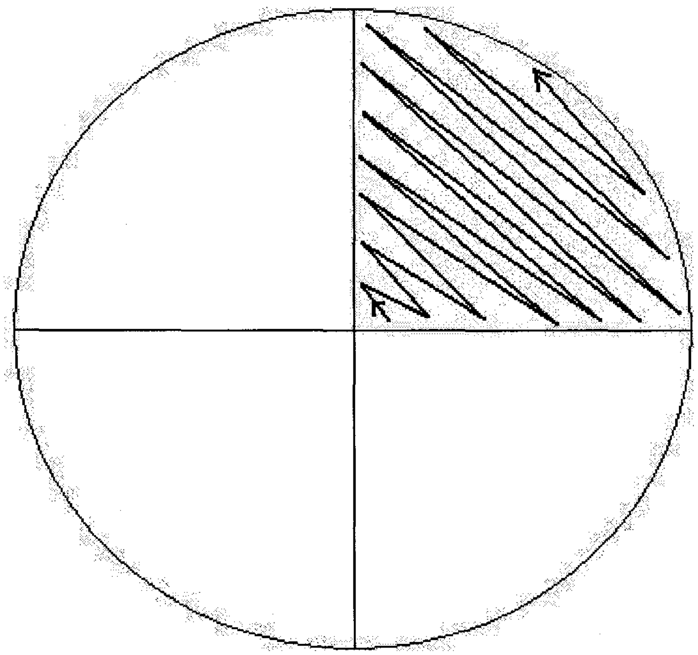

Figure 3.2 **Diagram of searching technique used within search plots. Plots were separated into 4 quadrants, each quadrant being walked in the zig-zag pattern shown while searching for carcasses.**

through logistic regressions using Statistica v.6.1. AIC_c models in this experiment were created based on commonalities between variables in order to generate realistic models. The first model was based on *bird characteristics*, and contained size as well as level of conspicuousness data on each carcass. The second model contained information related to the *ground cover* within a 0.5 meter radius of where the carcass was dropped. The variables were amount of bare ground, low standing vegetation (LSV – short grasses, mosses, lichens and other short vegetation), shrubs, tall grasses, and logs or other large woody debris. The third model contained information related to *searcher experience* which contained information related to the number of times each searcher had searched previously. The fourth model was comprised of data related to *weather*. This model contained the variables average temperature (°C), average cloud cover (in increasing categorical levels of cover), and average wind (km/h). The fifth model contained all the variables. I ran a final model with variables found to be significant from the first four models. This last *significant variable* model was compared against all the previously listed models to determine whether combinations of variables from different categories interacted to predict more variation in carcass detections than the others. Models were considered a good fit when the delta AIC_c was less than 2 (Anderson et al. 2000). AIC_c values were calculated using the following equation found in Burnham et al. (2001),

$$AIC_c = -2(\theta) + 2K + \frac{2K(K+1)}{(n-K-1)}$$

Where θ is the log likelihood, K is the number of variables and n is the sample size.

To determine whether or not the variables found to be significant could be used to create a correction model, I first tested in the internal validity of the model using the receiver operating characteristic analysis (ROC). ROC values ranging from 0.5 to 0.7 were considered to have low model accuracy, 0.7 to 0.9 good model accuracy, and > 0.9 high model accuracy (Swets 1988, Manel et al. 2001). I then performed cross-validation to test the external accuracy of the model. Data from fall 2006 and spring 2007 were used to create the model (learning set). The derived model was then used on novel search data from fall 2007 (test set) to determine whether I could accurately predict whether searchers found or failed to find carcasses, based on weighting of different variables. Models that were able to predict whether or not a carcass was found with more than 70% accuracy were considered good and could therefore effectively be used as correction models, which are created using coefficients obtained from logistic regression analysis.

3.4 Results

3.4.1 Anecdotal Observations

Searchers found 54% of the carcasses placed in search plots. Of the larger sized birds (larger owls, eagles, hawks and waterfowl), 77% were found, compared to 42% of small (kinglets, sparrows and warblers) and medium sized birds (saw-whet owls and northern flickers) combined. When brightly coloured carcasses (characterized by having a conspicuous level of more than 50%) were placed in search plots, 62% were recovered during searches, whereas only 45% of less brightly coloured birds were found.

3.4.2 Attributes of the Bird

Size and *conspicuousness* (model 1.3) together had lowest delta AIC_c (0) and the highest weight (~63.7%) of all of the models (Table 3-1). Because of these numbers, these two variables were the first to be included in the *Significant Variable Model.*

3.4.3 Attributes of Ground Cover

The model containing *% shrub* and *% tall grass* (model 2.3) had the second lowest delta AIC_c score (2.31) and the second highest weight (~20%) during the running of the first AIC_c (Table 3-1). Even though the delta AIC_c value is greater than 2, this smaller model (only two variables) combined with the model above is capable of explaining close to 84% of the variability, while maintaining parsimony. Because of this, the variables within this model were also included in the *Significant Variable Model.*

3.4.4 Full vs. Significant Variable models

When the performance of all the previous models was tested against a *full model* (containing all variables) and the *significant variable model* (containing only those variables mentioned above, determined to be the highest contributing variables within each category), the *significant variable model* proved to have the highest weight and the only model with a delta AIC_c of less than 2 (Table 3-2).

During the ROC analysis, recorded values were compared with values predicted using the *significant variable model.* The ROC curve showed an area under the curve of 0.80

Table 3-1 Initial AIC models under Attributes of the bird, ground cover, weather, and searcher experience affecting whether or not a carcass is found. The model with all ground cover variables had the lowest ΔAIC_c, however the model containing % conspicuousness and length from beak to tail (cm) also had ΔAIC_c below 2.0.

	log likelihood	AIC	ΔAIC	weight
Attributes of the bird				
Model 1.1 - % conspicuousness	-66.75	135.54	4.23	0.07
Model 1.2 – length from beak to tail (cm)	-67.60	137.24	5.94	0.03
Model 1.3 - % conspicuousness & length from beak to tail (cm)	-62.53	131.31	**0.00**	0.63
Attributes of ground cover				
Model 2.1 - % low standing vegetation	-70.02	142.08	10.77	0.00
Model 2.2 - % low standing vegetation & % bare ground	-69.18	144.59	13.28	0.00
Model 2.3 - % shrub & % tall grass	-63.69	133.62	**2.31**	0.20
Model 2.4 - % low standing vegetation & % bare ground & % shrub & % tall grass & % log & % tree & % water	-60.57	138.66	7.35	0.01
Model 2.5 - % bare ground	-71.68	145.39	14.08	0.00
Attributes of weather				
Model 3.1 – average temperature & average wind & average cloud	-67.23	142.86	11.55	0.00
Model 3.2 - average temperature	-71.77	149.87	18.56	0.00
Model 3.3 - average wind	-68.07	138.18	6.88	0.02
Model 3.4 - average cloud	-70.37	142.79	11.48	0.00
Attributes of searcher experience - Searcher (Model 4)	-69.56	141.15	9.84	0.00

Table 3-2 Second AIC model set adding full model and a model composed of the main significant effects from Table 1. The full model had the lowest ΔAIC_c as well as the only ΔAIC_c below 2.0.

	log likelihood	AIC	ΔAIC	weight
Attributes of the bird				
Model 1.1 - % conspicuousness	-66.75	135.54	12.88	0.00
Model 1.2 – length from beak to tail (cm)	-67.60	137.24	14.59	0.00
Model 1.3 - % conspicuousness & length from beak to tail (cm)	-62.53	131.31	8.65	0.01
Attributes of ground cover				
Model 2.1 - % low standing vegetation	-70.02	142.08	19.42	0.00
Model 2.2 - % low standing vegetation & % bare ground	-69.18	144.59	21.93	0.00
Model 2.3 - % shrub & % tall grass	-63.69	133.62	10.96	0.00
Model 2.4 - % low standing vegetation & % bare ground & % shrub & % tall grass & % log & % tree & % water	-60.57	138.66	16.00	0.00
Model 2.5 - % bare ground	-71.68	145.39	22.73	0.00
Attributes of weather				
Model 3.1 – average temperature & average wind & average cloud	-67.23	142.86	20.20	0.00
Model 3.2 - average temperature	-71.77	149.87	27.21	0.00
Model 3.3 - average wind	-68.07	138.18	15.53	0.00
Model 3.4 - average cloud	-70.37	142.79	20.13	0.00
Attributes of searcher experience – Searcher (Model 4)	-69.56	141.15	18.50	0.00
Full model – all above variables (Model 5)	-46.70	126.12	3.46	0.15
Significant variable model – Length from beak to tail (cm); % conspicuousness; % shrub; % tall grass (Model 6)	-56.02	122.66	**0.00**	0.83

(Figure 3.3), showing that this model has good accuracy (Swets 1988, Manel et al. 2001). Cross-validation showed high predictive ability, accurately predicting found carcasses 73.68% of the time and accurately predicting carcasses not to be found 90.9% of the time (Table 3-3).

The variables determined to be significantly contributing to whether or not a carcass is found were then paired with their respective coefficients, determined during logistic regression, to create a model for predicting the searcher efficiency (or of finding a carcass during a search):

$$p = \frac{e^{\mu}}{1 + e^{\mu}}.$$

Where μ = -1.07 + 0.02(% conspicuous) + 0.03(size from beak to tail) – 0.89(% shrub) – 0.07(% tall grass).

3.5 Discussion

The size of the bird from beak to tail (cm), the level of conspicuousness, and the percent of the ground cover containing tall grasses and shrubs all appear to have a moderate effect on whether or not a carcass is found, especially when they are combined in one model. Moreover, the *Significant Variable Model* (comprised of the variables above) was capable of explaining the most variability in search efficiency. When examining the applicability of these findings, the *Significant Variable Model* was capable of producing a

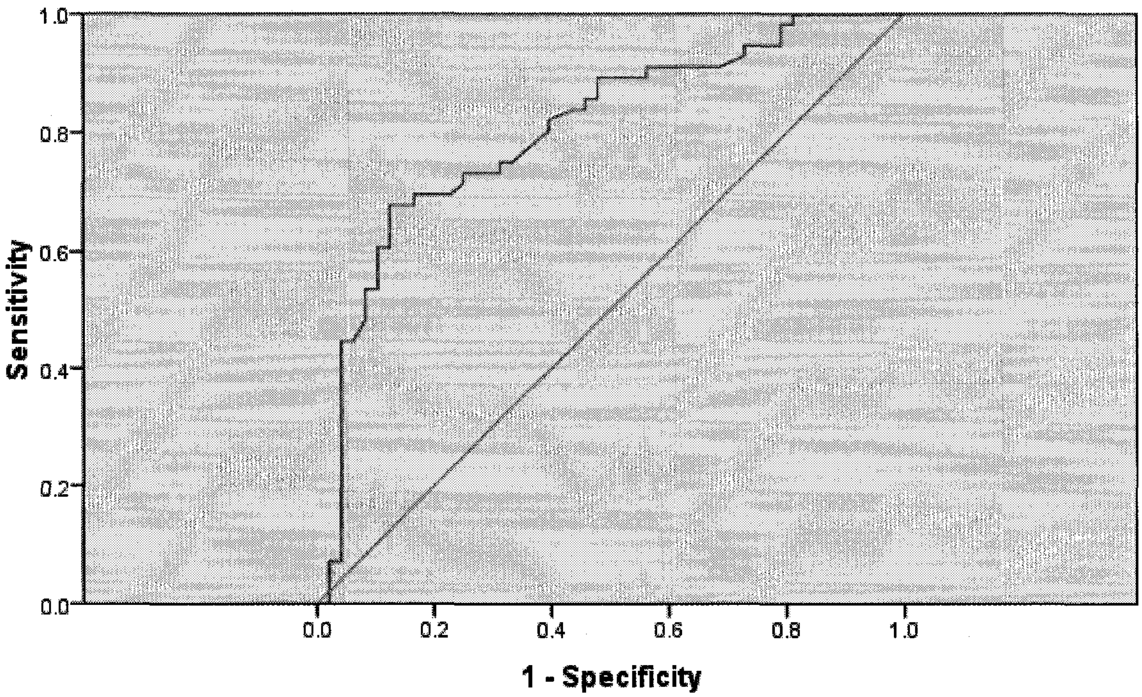

Figure 3.3 **Receiver operating characteristic analysis (ROC curve) of the *Significant Variable Model* showing the sensitivity (true positive) vs. 1-specificity (false positive). The area under the curve is 0.804.**

Table 3-3 Cross-validation results using the *Significant Variable Model* showing percent correct prediction for both found and not-found carcasses

		Observed		
		Found	Not Found	Percent Correct
Predicted	Found	14	5	73.68
	Not-Found	1	10	90.91

model (reported above) accurate enough to have good predictive ability of classifying carcass recovery in known experiments.

In terms of carcass characteristics, carcasses of larger size were more likely to be found than those of smaller sizes. This may be due to the searchers' ability to more easily detect a larger-sized carcass than a smaller one. Morrison (2002) states that most small birds are missed during searches and that numbers are 50-75% underestimated. Anderson et al. (2004) also found that smaller birds were significantly less likely to be found than larger birds in any type of vegetation (shrubs or tall grass). Larger carcasses were more likely to be detected than smaller carcasses in this study; however this poses an even larger problem. In a related study (Chapter 2), I found that smaller carcasses were removed more often by scavengers than larger carcasses. When combined with patterns that smaller carcasses are found less often than larger carcases (this study), the result is compounded. If mortality of small-sized birds is occurring at a wind farm site, documenting it may prove to be quite difficult. This could greatly bias the monitoring results, leading to an inaccurate image of the effect of the installation on certain bird populations.

Carcasses with a higher level of conspicuousness were more likely to be detected more than less conspicuous ones. Again, this can be attributed to the ease with which a searcher will notice or detect a brightly coloured bird, as opposed to those whose colours cryptically blend into the background. This is also seen in the popular peppered moth example where more conspicuous (lighter) moths stood out (and were predated upon) more than less conspicuous (darker) moths (Grant et al. 1996). In a study performed by

Witmer et al. (1995), the most conspicuously coloured carcasses were recovered in the greatest proportion. This variable was not significant in the carcass removal experiments (Chapter 2) and therefore does not lead to a compounding effect on less conspicuously coloured birds. It does, however, have an impact on determining which species of birds are being most affected by turbine collisions. If a particular species of bird with dull plumage is often colliding with turbines, this event may be underestimated as these birds are more difficult to locate during searches. If the bird is also small, there is an even greater chance that it will not be found, and also a greater chance that it will be scavenged – making it even more likely that the high levels of collisions experienced by 'little brown birds' will be overlooked, potentially leading to detrimental consequences for non-conspicuous species.

Shrubs and tall grasses appear to play a large role in searching efficiency. When the 5 meter radius surrounding the carcass had high percentages of tall grasses and shrubs, searching efficiency is lower than in those with low percentages of these types of vegetation. In a study conducted by Fowler et al. (1997), searches performed on beaches with more complex ground cover (such as rocks) had much lower carcass detections than searches performed on beaches consisting of only sand. Higher proportions of shrubs and tall grass at the placement site contributed to a smaller number of birds being successfully found. Wobeser et al. (1992) suggest searchers tend to have low efficiency when trying to detect extremely inconspicuous carcasses in dense vegetative cover. In another study, Higgins et al (1995) found a vegetation effect with searching efficiency, recording an 81.8% recovery of carcasses in cropland, and 63.3% recovery in grassland. Denser vegetation seems to cause a deterioration in the detection of carcasses. When comparing this finding with those found in Chapter 2, a problem arises. The obvious solution to a decrease in searcher efficiency caused by dense vegetation would be to remove this vegetation in the searching areas. However, in the study described in Chapter 2, I found that bare ground increases the level of carcass removal by scavengers, more than likely due to the same reasons that searchers are more capable of finding carcasses without dense vegetation. Therefore, modifying the ground cover to increase searching efficiency would also increase the likelihood of carcasses being removed, which would not be a very beneficial or practical solution.

Interestingly, searcher experience was not a significant variable in explaining searcher efficiency. Without knowing this, it might have been assumed that searchers with more experience would be better at locating carcasses, and many hours of training or practice might have been undertaken in order to attain a higher level of experience. Knowing that the level of experience does not contribute to a higher searching success rate means that only a minimum amount of time needs to be invested in training, saving time and resources. Instead, other observations and data recording could be conducted such as more time devoted to either radar monitoring to model migration in the area, or point counts and transects in order to assess the local bird community.

As discussed in Chapter 2, some of the variables determined to negatively affect searcher efficiency, such as high percentages of bare ground, positively affect carcass removal. In real life situations where modifications to ground cover must be made in order to maximize one's chances of recording the most realistic carcass information, decisions must be made with respect to balancing these variables. Much attention has been given lately to a new technique: using dogs to aid in searches (Peer et al. 2001) to increase searching efficiency. Studies have shown that efficiency increases when using dogs, causing the ratio of recovered to missed carcasses to go from 1:1 (with human searchers) to 12:1 with dogs in dense vegetation searching for smaller-sized birds (Homam et al. 2001). Efficiency in humans is hindered by increases in density and height of vegetation, whereas dog-searching efficiency remains the same in these conditions (Arnett 2006). Although human and dog searching efficiency is relatively similar within 10 meters of the turbine, the discrepancy in efficiency is seen as searchers move further away from the turbine base (Arnett 2006). This may be due to a loss of concentration by human searchers, or perhaps the larger searching areas found further from the turbine base leave more unchecked areas where carcasses could be missed. Dogs seem to offer an effective way to increase searcher efficiency without modifying any ground cover, however, if carcasses are removed very quickly (within 24 hours) as Chapter 2 suggests, even increasing efficiency by using dogs will not produce an accurate image of the impacts on bird populations.

Identifying the variables that affect searcher efficiency is only the first step in solving the problem of accurately assessing impacts at wind installations. The more pressing concern is whether these variables can be used to derive correction factors that can be used to gain a better understanding of turbine impacts. In order to determine whether or not the *Significant Variable Model* was capable of doing this, I used ROC analysis and cross-validation. The model showed good internal and external accuracy, and therefore good predictive power. One of the potential reasons for the good predictive power of this model is that it is a very parsimonious one, containing only a small number of the total variables tested against searcher efficiency. In a more parsimonious model, there are fewer variables, creating a simpler model with which predictive power may sometimes be stronger than the less parsimonious model (Stewart 1993). Having a model capable of predicting searcher efficiency means that a greater understanding of the variables affecting findability is gained and can be used to better understand how bird populations are being impacted by wind turbines.

3.5.1 Management Strategies

The variables that influenced detection rates in my study are likely to affect detection rates at many installations. Smaller-sized birds whose plumage does not contrast greatly with the background will be less likely to found. Similarly, areas containing higher proportions of shrubs and tall grasses within the vegetation will have a higher probability of producing missed carcasses during searches. However, while these variables should be collected during searcher efficiency trials at each site, the relative influence of these variables is likely to vary across sites. Local correction factors will have to be derived through a similar controlled study as outlined here.

Once conducted, AIC and logistic regression can allow managers to determine the local variables that influence detection, and use these to develop correction factors, possibly through the use of sightability models that are designed to compensate for biases in detection of targets (Samuel et al. 1987, Unsworth et al. 1990, 1999).

As well as using predictive models, managers could test bird species known to use the area against the bird characteristic variables found to affect searching efficiency. If there are many birds which fall into the category of being likely missed in a management area, perhaps more intense searching methods could be utilized (dog searches, longer searches).

Chapter 4 GENERAL CONCLUSION

Despite positive benefits in clean energy generation, wind installations have the capacity to cause harm to the biological environment that surrounds them (Kuvlesky et al. 2007; Kunz et al. 2007). Sometimes the harm is quite large (Orloff et al. 1992), with many turbine-collision related fatalities and massive avoidance behaviour, while other times very few collisions are recorded and no change in migration behaviour is seen (NWCC 2001). It is clear that our understanding of what causes a particular wind installation to be dangerous as opposed to less invasive is not very robust.

Optimally, techniques will be developed which will allow pre-construction monitoring results to predict direct and indirect impacts seen by the wind installations. With these techniques, avian migration behaviour as well as breeding bird population data could be recorded and analysed in a way that could predict whether or not a particular installation would have detrimental effects on its surrounding environment prior to the installation and operation of such an installation.

Unfortunately, there are no such techniques capable of relating pre-construction monitoring to post-construction fatalities. It is for this reason that post-construction monitoring must be conducted. The only true and proven method for determining the direct impacts of wind installations on bird populations is through carcass searching – physically counting each turbine-fatality. Without an accurate number of turbine-casualties, no amount of pre-construction monitoring could correctly determine impacts, and the effects on avian populations would not be fully understood. Furthermore, without being able to accurately record collisions, correlating pre-construction monitoring with actual impacts will not be possible. Accurate results are needed in order to reveal which monitoring techniques have high predictive abilities.

This thesis aimed to determine how to maximize the predictive ability of post-construction carcass searches so that the true impacts on avian communities can be understood and perhaps mitigated. Currently, correction factors are generally applied to post-construction carcass searching trial results in order to correct for the two big inhibitors of accurate carcass searching: carcass removal and searching efficiency. However, in order to truly determine the extent of the effects of turbines on bird populations, the factors influencing removal and searching efficiency must be fully understood.

The findings showed that carcass scavenging is influenced by the size of the bird (length in cm from beak to tail), the amount of bare ground surrounding the location of the carcass, and the Julian day (season). Searching efficiency is influenced by the size of the bird, the level of conspicuousness of the bird's plumage, and the amount of tall grass and shrubs present at the drop site of the carcass. Understanding that these factors play a role in accurately recording the number of turbine fatalities leads to the possibility of creating variable-weighted correction factor models to predict what searchers were not able to find due to inefficiency or scavenging. This understanding also creates the potential for the development of techniques or habitat modifications to maximize the accuracy of what is being deduced from carcass searching results.

Both models (explaining carcass removal as well as searching efficiency) were shown to have high predictive abilities. Two models were created in this study to predict scavenging likelihood and searcher efficiency. It is important to note that both variable-weighted correction factors should be used whenever estimating carcass numbers. Correcting for scavenging and not for searching efficiency (or *vice versa*) will not address all of the problems associated with obtaining accurate results. Using a program created for improving population estimates of elk from aerial surveys by means of variable-weighted models (Aerial Survey 1999), it is likely that these models could be used together to improve true carcass estimates based on biases contributing to both searcher efficiency and carcass removal.

Using predictive models is not the only strategy that can be concluded from this study. Correction coefficients could be used to classify management areas under varying levels of risk (risk associated with not recovering a carcass during a search or with a carcass being removed prior to searches). The characteristics of bird species known to use the management area could be tested against those characteristics known to increase their risk of being scavenged or not being found. The same process could be performed with respect to ground cover. Through this process, key species and areas could be identified as being at risk not being recorded if collisions occur and managers could then take action to minimize the chances of this happening (dog searches, longer searches, more frequent searches, directed bird surveys to at risk species, etc…). Being able to predict not only how many unfound carcasses were missed (whether due to inefficiency or removal) is important, however understanding more about the characteristics of those birds is even more helpful. Comprehending that the birds missing from carcass searches are not evenly distributed among size and species of bird and are instead mostly composed of smaller, less brightly coloured birds is important when determining how specific populations of birds are being impacted by the wind installation.

The danger of overlooking direct impacts to small birds is shown in this study to be a real possibility. Smaller sized birds are scavenged more rapidly and more often than larger sized birds. They are also missed more often during carcass searches. This means that the quantity of small birds being affected by turbines may be underestimated. If planners and environmental assessors have this knowledge, they may be more sensitive, ensuring that an acceptable amount of information is known about populations of birds in the area of concern meeting this criterion.

Beyond creating correction factors with variable-weighted models, the information uncovered in these studies could be used to maximize carcass recovery in the first place. However, it does seem that some of the variables influencing carcass removal and searching efficiency counteract each other. Bare ground increases scavenging of carcasses, reducing carcass recovery and increasing the need to correct these values. High percentages of tall grass and shrubs surrounding the carcass drop site decreases searching efficiency, also reducing carcass recovery and increasing the need for correction. Modifying the ground cover in order to maximize searching efficiency would be possible by maintaining extremely low levels of vegetation around the turbine bases. This, however, would increase carcass removal by scavengers. This solution alone would not be sufficient; however pairing habitat modification with other techniques may be possible. Fencing the area under the turbine may inhibit non-avian scavengers from accessing the area, making the fact that bare ground increases scavenging activity less important. However, fencing along with habitat modification may be expensive to install and maintain under every turbine. Perhaps high risk turbines could be identified either through pre-construction monitoring of migratory pathways or through recording high turbine-casualties during post-construction monitoring. These turbines would represent only a small proportion of the total number of turbines present at the wind installation, and monitoring them through habitat modification and fencing would reduce the need to monitor every turbine in this way, while still monitoring high risk areas.

Another potential option, if habitat modification is not a viable choice either because of cost or because of increasing in scavenging, dogs could be used in searches (Arnett 2006). Dogs are attracted to carcasses through smell and are therefore not deterred by different kinds of ground cover. However as mentioned earlier, training, purchasing, and keeping carcass-searching specific dogs could be expensive as well as operationally difficult.

In summation, it is our hope that the findings of these studies will be implemented in environmental assessments of wind installations to arrive at a better estimate of the number of birds killed and gain a better understanding of how avian populations are being affected at these areas. Perhaps if all assessments begin to use variable-weighted predictive models to improve carcass estimates as well as use the variables determined in this study to reveal which birds are at risk of being missed due to removal or searcher inefficiency, a better understanding of the direct impacts on birds will be gained. Furthermore, if habitat modification and/or dog-searching could be used in conjunction with these predictive models, the likelihood of missing carcasses due to either scavenging or searching efficiency would be greatly reduced, and any that would be missed would be accounted for through the use of predictive models. Additionally, it is possible that these findings could be applied to bat carcass searches. Ground cover findings would apply equally to bats and mitigation measures (keeping vegetation low) may help in carcass searches. Findings concerning size and conspicuousness indicate that bat carcasses may be very hard to find as well as removed quickly by scavengers because they are both small and inconspicuously coloured.

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